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Rating Procedure for Mixed Air-Source Unitary Air Conditioners and Heat Pumps Operating in the Cooling Mode - Revision 1

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RATING PROCEDURE FOR MIXED AIR-SOURCE UNITARY AIR CONDITIONERS AND HEAT PUMPS OPERATING IN THE COOLING MODE - Revision 1

Abstract

A procedure is presented for determining the cooling performance ratings of air-source unitary air conditioners and heat pumps consisting of a condensing unit and an indoor section which were not tested together as a system. The procedure allows calculation of capacity at the 95°F rating point and seasonal energy efficiency ratio, SEER, using as a reference point performance ratings of the condensing unit tested under current DoE procedures in conjunction with a different indoor section. This procedure has been prepared for the Department of Energy for consideration in the rule making process. It is a revised version of the original version of the procedure published in 1986.

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BACKGROUND

The first version of the rating procedure for mixed air conditioners and heat pump systems operating in the cooling mode was published by the National Bureau of Standards (renamed in 1988 to National Institute of Standards and Technology, NIST) in 1986 [1]. The development background of the procedure was presented in a separate publication [2].

It has always been recognized that rating parameters can be more accurately determined from a laboratory test than from a calculation procedure. It has also been recognized that a better calculation procedure can be formulated with unrestricted availability of matched system data than with limited data availability. Development of a satisfactory rating procedure requires a balance between accurate mixed-system performance prediction and the needed effort to obtain data and perform the rating calculations.

The verification process of the first version of the procedure and comments received from the industry indicated that there was not as much concern with the main rating correlations as with the way two kinds of input data, coil capacity and refrigerant mass flow rate through a short tube restrictor, had to be obtained. A study performed by NIST resulted in a change of the procedure in one of these two areas while in the other it appeared to be impractical to modify the procedure. Consequently, this revised version of the procedure is for the most part identical with the original document. Changes introduced to the procedure are explained below.

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Indoor Coil Capacity Determination.   Laboratory verification of the procedure
showed that for systems with a mixed indoor coil of significantly greater
cooling capacity than a matched coil (30% and more), predicted ratings tended
to exceed the laboratory obtained values by more than 7%. The indication was
that the indoor coil scaling factor, obtained by taking a ratio of the mixed
coil capacity to the matched coil capacity, as read from a coil catalog, did not
accurately reflect the relative performance of larger mixed coil.

As larger indoor coils are more likely to be installed in configurations which
could affect the air velocity profile, NIST performed a study in which a
single-slab coil was tested at various air velocity profiles [3]. The capacity
of the tested coil depended heavily on the air distribution. The capacity
degradation was found to be as much as 26 percent.

The evaporator coil capacity tests with various air velocity profiles provided
convincing evidence that in order to predict coil capacity more accurately, a
coil capacity prediction method has to take into account the air flow distribution
at the coil face. Consequently, an evaporator model was developed which is
sensitive to the air velocity profile [4]. The model is based on a tube-by-
tube scheme. This modeling method allows simulation of refrigerant distribution
between different circuits, which is also dependent on the air velocity
profile. The model was verified against laboratory data reinforcing the
evidence that the air flux maldistribution is the primary reason for coil
capacity degradation from its maximum value.

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Parallel to the model development effort, a study was performed to determine if "typical" air velocity profiles could be found for "typical" coil configurations (V-shape, A-shape, slanted) to be used as input to the evaporator model to establish corresponding "typical" capacity degradation factors. This experimental study showed that the air flow distribution at the coil is a combined function of the coil angle and duct configuration. The sensitivity of the flow to relatively simple geometry constraints (like distance from the duct inlet) and the variability in indoor coil design indicated that it was not feasible to establish typical values of capacity degradation factors within the time frame assigned for the project, if at all. For this reason, this revised version of the procedure does not provide a new method for coil capacity evaluation but rather maintains the applicability limit for the coil scaling factor equal 0.8 - 1.3.

Determination of Mass Flow Rate through a Short Tube Restrictor. For years the capillary tube had been the predominant expansion device in air conditioning applications. In the eighties, the short tube restrictor has gained substantial popularity and has been used by several major manufacturers. At the time the original rating procedure for mixed systems [1] was developed, a well established correlation for mass flow rate prediction for short tube restrictors was not available. In these circumstances an approximate, semi-theoretical correlation was derived and included in the procedure.

Recently an experimental study [5] was completed at NIST in which mass flow rate dependency on the inlet pressure, subcooling, and outlet pressure was studied for short tubes of various diameters, lengths, and inlet and outlet

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geometries. The mass flow rate correlation developed in this study is used in this revised version of the procedure.

Other Changes.   The revised version of the procedure has the same format and section numbering as the original [1]. Other changes made to the document are mostly editorial, with the exception to imposition of applicability limits (recommended or mandatory) to the sizes of the mixed indoor coil and expansion device. Mandatory limits cannot be exceeded due to possible significant loss of accuracy of the rating correlations. Recommended limits indicate the applicability range beyond which reliability of the compressor may be affected. The applicability limits of this rating procedure should not be construed as those within which reliable operation is unquestionably certain. These applicability limits are based on the refrigerant charge information obtained from a simulation study [4] and industry comments.

1. PURPOSE

The purpose of this report is to establish procedures for determining the cooling performance ratings of air-source unitary air conditioners and heat pumps consisting of a condensing unit and an indoor section which were not tested together as a system. The performance ratings covered in this document are the cooling capacity at Test A conditions and seasonal energy efficiency ratio, SEER, as defined by the DoE Test Procedures contained in Appendix M to Subpart B of the Code of Federal Regulations [6]. This rating methodology is a composite of independent measurements and calculations made on an outdoor unit in conjunction with a matched indoor coil, and a mixed indoor coil.

2. SCOPE

This procedure applies to residential air-conditioning and heat pump systems charged with Refrigerant 22, consisting of an indoor air-cooling coil assembly and an outdoor single-phase, electric, air-source unit whose matched system* cooling capacity** is less than 65,000 Btu/h (19,050 W). This procedure does not apply to systems employing multispeed compressors, or systems in which compressor control strategy changes with load (e.g., cylinder unloads, hot-gas bypass). Additional limitations as to the quantitative range of the scope of this document are given in Section 4.2.2 and 4.3.2.

3. DEFINITIONS

All definitions included in or cited by Title 10, Part 430 of the Code of Federal Regulations [6] shall be considered part of this procedure in addition

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*Refer to Section 3, Definitions.
**As defined by DoE Test Procedures, Appendix M to Subpart B of [6].

to the following definitions.

3.1 ARI - Air Conditioning and Refrigeration Institute.

3.2 Air Source Unitary Air Conditioner or Air Source Unitary Heat Pump or Unitary System - an outdoor unit combined with an indoor coil assembly.

3.3 Outdoor Unit - an assembly of refrigerating components designed to compress and liquify a specific refrigerant. It consists of refrigerant vapor compressor, air-cooled refrigerant coil, coil fan and motor, and regularly furnished accessories. A liquid line solenoid valve and other cyclic performance-enhancing devices (excluding the expansion device itself), if included in an air-conditioner or heat pump, are considered to be a part of the outdoor unit.

3.4 Indoor Coil Assembly - an assembly consisting of a coil, condensate collecting pan, and expansion device, and which may or may not include a blower, motor and cabinet.

3.5 Matched Coil - an indoor coil which is a part of the matched system.

3.6 Matched System - a unitary system which has been tested and rated in accordance with Appendix M to Subpart B of Title 10, Part 430 of the Code of Federal Regulations [6].

3.7 Mixed Coil - an indoor coil which is used in a unitary system instead of the matched coil.

3.8 Mixed System - a unitary system which is not a matched system.

3.9 Shall - where 'shall' or 'shall not' are used for a provision specified, that provision is mandatory if compliance with the procedure is claimed.

3.10 Should, Recommended, or It Is Recommended - 'should', 'recommended', or 'it is recommended' are used to indicate provisions which are not mandatory but which are desirable as good practice.

4. PROCEDURE FOR RATING MIXED SYSTEM

4.1 Rating Correlations

Mixed system capacity at DoE Test A condition, Q_x, shall be calculated using equation 4.1. Mixed system Seasonal Energy Efficiency Ratio, $SEER_x$, shall be calculated using equations 4.2, 4.3, and 4.4 (derivation of these equations is presented in [2]).

$$Q_x = \left[Q_m + 3.413 \cdot P_{F,m} \right] \cdot F_c^{0.37} \cdot F_e^{\alpha} - 3.413 \cdot P_{F,x} \tag{4.1}$$

$$SEER_x = SEER_m \left(\frac{Q_x}{Q_m} \right)_{82}^{-1} \cdot \left(\frac{P_x}{P_m} \right)_{82}^{-1} \cdot F_{TXV} \tag{4.2}$$

$$\left(\frac{Q_x}{Q_m} \right)_{82} = \left[1 + \frac{3.25 \cdot P_{F,m}}{Q_m} \right] \cdot F_c^{0.35} \cdot F_e^{\alpha} - 3.25 \frac{P_{F,x}}{Q_m} \tag{4.3}$$

$$\left(\frac{P_x}{P_m} \right)_{82} = 0.8 \cdot F_c^{0.14} \cdot F_e^{\beta} + 0.1 \frac{P_{F,x}}{P_{F,m}} + 0.1 \tag{4.4}$$

Symbols used in equation 4.1, 4.2, 4.3 and 4.4 are explained below.

Exponents

    $\alpha = -0.15$ for $F_e \geq 1$

    $\alpha = 0$ for $F_e < 1$

    $\beta = 0$ for $F_e \geq 1$

    $\beta = -0.2$ for $F_e < 1$

Other Symbols

F_c = indoor coil scaling factor calculated as explained in section 4.2.1

F_e = expansion device scaling factor calculated as explained in section 4.3.1

F_{TXV} = thermostatic expansion valve factor. (Shall be evaluated as shown in Table 1).

$P_{F,m}$ = power input to the indoor fan of a matched system as defined in section 4.4.1 (watt).

$P_{F,x}$ = power input to the indoor fan of the mixed system as defined in section 4.4.2 (watt).

Q_m = capacity of the matched system at Test A as certified by its manufacturer (Btu/h).

Q_x = capacity of a mixed system at Test A, as calculated by equation 4.1 (Btu/h).

$\left(\dfrac{Q_x}{Q_m} \right)_{82}$ = ratio of capacities at Test B conditions of the mixed and matched system.

$\left(\dfrac{P_x}{P_m} \right)_{82}$ = ratio of power inputs at Test B conditions of the mixed and matched system.

$SEER_m$ = seasonal energy efficiency ratio of the matched system (Btu/(h · watt)) as certified by its manufacturer.

$SEER_x$ = seasonal energy efficiency ratio of the mixed system (Btu/(h · watt)) as calculated by equation 4.2.

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4.2 Indoor Coil Scaling Factor

4.2.1 Determination of the Indoor Coil Scaling Factor

The indoor coil scaling factor, F_c, is defined by the following equation:

$$F_c = \frac{Q_{c,x}}{Q_{c,m}} \tag{4.5}$$

where:

$Q_{c,x}$ = cooling capacity of a mixed coil at the air mass flow rate specified for the mixed system. The air mass flow rate specified for the mixed system shall satisfy conditions of Appendix M to Subpart B of [6].

$Q_{c,m}$ = cooling capacity of a matched coil at the indoor-air volumetric flow rate, CFM_m (ft^3/min), at which matched system capacity, Q_m, was measured. If CFM_m information is not available, the value for the indoor air volumetric flow rate shall be calculated as follows:

$$CFM_m = \frac{Q_m}{12000} \cdot 425 \ (ft^3/min). \tag{4.6}$$

Capacities of matched and mixed coils shall be obtained using the same verified method (see Section 4.2.3). Coil capacities shall be obtained at the following conditions:

- inlet air conditions - 80°F dry bulb/67°F wet bulb

- refrigerant saturation temperature at the evaporator outlet - 45°F

- identical refrigerant superheat at the evaporator outlet

If coil capacities are obtained by means of a catalog or computer

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simulation, the same catalog or computer simulation shall be used for both coils. Coil material and geometry (e.g., inside tube diameter, tube staggering, fin spacing, fin thickness, fin shape, and number of tube rows) shall be accounted for by the method used. That is, the methodology used must have these parameters as independent variables.

4.2.2 Restrictions

The acceptable range of values for the indoor coil scaling factor, F_c, is from 0.8 to 1.3. This rating procedure shall not be used if the indoor coil scaling factor is smaller than 0.8. If the ratio $Q_{c,x}/Q_{c,m}$ results in a value greater than 1.3, the value of the indoor coil scaling factor, F_c, shall be 1.3. If the rating is calculated for a heat pump system able to operate in the heating mode, two additional conditions should be satisfied:

1. The internal volume of the mixed indoor coil assembly should be within 100-120 percent of the internal volume of the matched coil assembly, or should not exceed the volume of the largest coil certified with a given condensing unit by the condensing unit manufacturer, whichever is larger.

2. Condensing capacity of the mixed coil should be within 100-120 percent of capacity of the matched coil, or should not exceed the capacity of the largest certified coil, whichever is larger.

4.2.3 Verification of Coil Capacity Determination Method

A variety of methodologies exist for calculating the capacity of a coil based on material and geometry data only. For example, several large heat exchanger manufacturing companies publish catalogues of performance curves for their

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specific products which are commonly used in a generic fashion. That is, the capacity of coils of the same materials and of the same number of rows, tube patterns and diameters, fin spacing, shape, and thickness is assumed to be the same for all manufacturers. Similarly there exist many computer simulations which are based either on regression analysis of the above mentioned catalogue data or on first principles of the heat transfer phenomena involved. If a specific methodology of either of these categories has at least the independent variables listed above, it may be used in this procedure to predict the capacities of the coils (i.e., $Q_{c,x}$ and $Q_{c,m}$). However, the specific methodology chosen must be verified by test, in accordance with ASHRAE Standard 33-78 [7] and ARI Standard 410-81 [8], to demonstrate that it is sufficiently accurate to simulate the coil line which is being used in the mixed system rating.

This verification requires that, for a given coil line, the capacity range over which the methodology is used to predict capacity values must be straddled by at least two tests which are within 5% agreement with the predicted values. For example, if a manufacturer produces a line of coils with six sizes having capacities ranging from 20000 Btu/h to 33000 Btu/h and uses a single methodology (e.g., computer simulation) to predict the six individual capacity values, the methodology must be within 5% agreement with the test values of the smallest (20000 Btu/h) and the largest (33000 Btu/h) coil. A similar pair of tests straddling the matched coil is also required if the methodology has not been previously verified for that line.

A coil line is defined as a group of coils which are of the same materials and bonding procedure, configuration (i.e., flat or A-shape), row staggering, fin thickness, fin spacing, fin shape (i.e., flat, wavy, corrugated edge, etc.),

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tube diameters and internal surface finish. If any of these parameters differ, then a new coil line has been defined and a new verification test pair is required for the methodology.

It is recognized that different numbers of tube rows and circuitry are not being considered as defining a new coil line; yet they probably have a significant effect on performance, all other parameters being held constant. However, the state of the art of coil performance simulation or representation is such that these variables are seldom considered. Some first principle computer simulation programs, such as the one used to develop this standard, do exist but they are not widely available and are usually so complex that input errors are easily possible. Therefore, it appears unreasonable to require this degree of sophistication for coil rating at this time.

4.3 Expansion Device Scaling Factor

4.3.1 Determination of the Expansion Device Scaling Factor

The expansion device scaling factor, F_e, depends on the type of matched and mixed expansion devices involved. It shall be determined using Table 1, which provides a value for the scaling factor or refers to the equation by which the scaling factor shall be calculated.

Table 1.   Evaluation of the Expansion Device Scaling Factor, F_e, and the Thermostatic Expansion Value Factor, F_{TXV}.

Expansion Device		F_e	F_{TXV}
Matched System	Mixed System		
TXV, no bleed	TXV, no bleed*	1.0	1.000
TXV, no bleed	TXV, w/bleed*	1.0	0.975
TXV, w/bleed	TXV, no bleed*	1.0	1.025
TXV, w/bleed	TXV, w/bleed*	1.0	1.000
Capillary or Short Tube Restrictor	TXV, no bleed**	1.0	1.050
Capillary or Short Tube Restrictor	TXV, w/bleed**	1.0	1.025
Capillary	Capillary	eq. 4.7	1.000
Capillary	Short Tube Restrictor	eq. 4.7	1.000
Short Tube Restrictor	Capillary	eq. 4.7	1.000
Short Tube Restrictor	Short Tube Restrictor	eq. 4.7	1.000

*the mixed TXV shall have equivalent capacity and same superheat setting as the matched TXV

**the mixed TXV shall have equivalent capacity as the matched expansion device

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4.3.2 Restrictions

This rating procedure shall not be used for any system if:

a) the expansion device scaling factor, F_{ex}, is outside the range 0.95-1.35.

b) the mixed system has a combination of capillary tubes or short tube restrictors connected in series.

c) the matched system has a combination of capillary tubes or short tube restrictors connected in series.

d) the matched system has a TXV and the mixed system has either a capillary tube or a short tube restrictor, unless the condensing unit manufacturer also certifies a system in which a TXV is replaced by a capillary tube or short tube restrictor type expansion device. In such a case, this system may be considered as a matched system and its performance data may be used for calculation of performance of the mixed system.

This procedure should not be used for systems able to operate in the cooling and heating mode if the expansion device scaling factor, F_{ex}, is outside the range 1.00-1.25.

4.3.3 Equations for Calculating Expansion Device Scaling Factor

The expansion device scaling factor, F_e, is the ratio of summations of refrigerant mass flow rates through the mixed ($m_{x,i}$) and matched ($m_{m,j}$) expansion devices, connected in parallel, at the same operating conditions.

$$F_e = \frac{\sum m_{x,i}}{\sum m_{m,j}} = \frac{m_{x,1} + m_{x,2} + \ldots m_{x,i}}{m_{m,1} + m_{m,2} + \ldots m_{m,j}} \qquad (4.7)$$

Subscripts x and m refer to mixed and matched expansion devices, and subscripts i and j correspond to the number of parallel connected capillary tubes or short tube restrictors in the mixed and matched expansion devices, respectively. The operating conditions selected for calculation of the expansion device scaling factor are: pressure of 250 psia and 13°F subcooling at inlet, and the saturation temperature of 45° in the evaporator.

Evaluation of the mass flow rate, m, depends on the type of flow restrictor. For a capillary tube the following equation shall be used:

$$m = 109.6 \cdot \Phi \qquad\qquad (4.8)$$

where Φ is the flow factor for the capillary tube employed, determined from its geometry with the aid of the ASHRAE Handbook, Equipment Volume, 1988, Chapter 19, Figure 39 [9].

Refrigerant mass flow rate through a short tube restrictor shall be calculated by the following equations [5]:

$$m = 15955 \cdot C_c \cdot D^2 \cdot (250 - P_2)^{0.5} \quad (lb/h) \qquad\qquad (4.9)$$

$$C_c = 1 + 0.104 \cdot DEPTH^{0.64} \cdot (L/D)^{0.27} \qquad\qquad (4.10)$$

$$P_2 = 209.92 \left[1.061 - 0.123 \cdot e^{-0.017 \cdot (L/D)^2} \right] \qquad\qquad (4.11)$$

where: D (inch) denotes the inner diameter and L (inch) denotes the length of the short tube restrictor. Symbol DEPTH (inch) denotes the depth of the inlet chamfer. The length dimensions required in the prescribed equation shall be measured by methods providing accuracy of $\pm$ 1.5%.

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4.4 Power Input to the Indoor Fan

4.4.1 Power Input to the Indoor Fan of the Matched System

Power input to the indoor fan, $P_{F,m}$, shall be measured in accordance with
Appendix M to Subpart B of [6], at the indoor-air volumetric flow rate, CFM_m,
at which capacity of the matched system, Q_m, was measured. If CFM_m information
is not available, the value for the indoor-air volumetric flow rate shall be
calculated by equation (4.6). If the indoor fan is not supplied with the
system, $P_{F,m}$ shall be evaluated by the equation:

$$P_{F,m} = 0.365 \cdot CFM_m \tag{4.12}$$

where CFM_m (ft^3/min) is a volumetric flow of air through the matched indoor
coil at which system capacity, Q_m, was measured.

4.4.2 Power Input to the Indoor Fan of the Mixed System

Power input to the indoor fan, $P_{F,x}$, shall be measured in accordance with
Appendix M to Subpart B of [6], at the indoor volumetric air flow rate, CFM_x,
at which capacity of the mixed system, Q_x, is evaluated. If the indoor fan is
not supplied with the system, $P_{F,x}$ shall be evaluated by the equation:

$$P_{F,x} = 0.365 \cdot CFM_x \tag{4.13}$$

where CFM_x (ft^3/min) is the volumetric flow of air through the mixed indoor
coil at which the capacity of the mixed system, Q_x, is to be evaluated.

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4.5 Values of Ratings

4.5.1 Values of Capacity at Test A

The capacity at Test A shall be expressed in Btu/h (W) in multiples of:

Capacities Btu/h (W)	Multiples Btu/h (W)
Less than 20,000 (less than 5,900)	100 (30)
20,000 up to 38,000 (5,900 up to 11,000)	200 (60)
38,000 up to 65,000 (11,100 up to 19,000)	500 (150)

The capacity value shall not exceed Q_x value as calculated by equation (4.1).

4.5.2 Values of Seasonal Energy Efficiency Ratio, SEER

The Seasonal Energy Efficiency Ratio, SEER, shall be expressed in multiples of 0.05. The Seasonal Energy Efficiency Ratio shall not exceed $SEER_x$ as calculated by equation (4.2).

5. ALTERNATIVE RATING PROCEDURE FOR MIXED SYSTEMS

The large number of variables and the complexities of their interactions associated with an air conditioner always make theoretical or quasi-empirical rating procedures less certain than a whole system test. Therefore, an acceptable alternative to this entire methodology is a formal certification program in which performance of a significant number of the mixed systems created by the use of a single coil line is measured.

This rating procedure was developed based on characteristics of equipment

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which was considered to be a "typical" system. Other rating procedures that may produce ratings of comparable or better accuracy would probably be those which were developed for specific production lines and/or are utilizing more input data on the matched and mixed components, if such data are available. Also some alteration of this rating procedure may be warranted if supported by test data of a given component (e.g. test data based correlation for an expansion device of a specific design).

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4. TITLE AND SUBTITLE

Rating Procedure for Mixed Air Source Unitary Air Conditioners and Heat Pumps
Operating in the Cooling Mode - Revision 1

5. AUTHOR(S)

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A procedure is presented for rating split, residential air conditioners and heat pumps operating in the cooling mode which are made up of an evaporator unit combined with a condensing unit which has been rated under current procedures in conjunction with a different evaporator unit. The procedure allows calculation of capacity at the 95°F rating point and seasonal energy efficiency ratio, SEER, without performing laboratory tests of the complete system. This procedure has been prepared for the Department of Energy for consideration in the rule making process. It is a revised version of the original version of the procedure published in 1986.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

air conditioner, central air conditioner, heat pump, mixed system, mixed-matched system, mixed system, rating procedures